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ANALYSIS OF BROOD STATISTICS

OF THE

WESTERN PINE BEETLE

(DENDROCTONUS BREVICOMIS LEC.)

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INTRODUCTION

At Bray, California, in 1913, J.D.Riggs spent a considerable period during the winter months in chipping away bark with his ax and counting the number of individual larvae of the western pine beetle (Dendroctonus brevicomis Lec.) that one good-sized tree might be expected to produce. He secured the figure 33,230 larvae and young adults as the result of his winter's labor.

Next, at Ashland, Oregon, in 1916, the writer became curious as to how many western pine beetles attacked per square foot of yellow pine bark surface, how many inches of gallery were constructed, how many eggs were laid and how many beetles emerged from the killed trees. The records taken of a fairly large series of trees gave the first statistics on all these various events and their relationships. Mr. J.M. Miller though the results shown by such counts would probably vary from year to year and might give an indication of what to expect in subsequent infestations. With this idea in mind a series of records was started and continued year after year; great quantities of bark were chopped up and the broods counted, and bark-count statistics started to pile up.

Now that eleven years have passed and over 4,000 square feet of bark put through the mill, it is about time to take stock of the evidence and decide whether or not we have learned anything from all this labor. And if so, what is it?

REVIEW OF LITERATURE

So far as is known, nothing has ever been published on statistical counts of the attack and emergence of forest barkbeetles. Hopping[1] carried on studies in Canada on the emergence of insects from infested yellow pine by caging the entire tree. While his method gave some interesting results, the few trees which could be studied in this manner precluded the possibility of drawing any general conclusions.

CLASSES OF RECORDS TAKEN

In general three classes of records were taken, each with a different purpose in view.

Beetle Statistics

The first work was done with the idea of determining how many beetles attacked a tree; how many attacks there were per square foot of bark surface; how many beetles there were to each attack; how long the egg galleries were; how many eggs a female beetle laid; how many beetles emerged from a tree; and other data of a similar nature that would give us an idea of the habits of these beetles and the way in which they do their work.

Trees were felled and the bark removed in rectangles of one or two square feet each. Colored pencils were used to check off the entrance, exit and ventilating holes, and a tally register employed to record the number. The length of egg gallery was measured with a cloth tape.

The results of this work have been summarized by Patterson in a report of 1924 and are not further considered in the present study.

Brood Counts

In this type of count the bark was shaved up and the beetles counted at different stages of their development in order to determine at what stage the greatest mortality occurred.

Under the supervision of Mr. J.M. Miller a great deal of this work has been done at Ashland, Oregon, and Northfork, California, and the results of this work as an indicator of brood mortality within the tree have been summarized by him in various reports.

Bark Counts

Bark counts consisted of counting the attacks, ventilating and exit holes on the surface of the bark from different parts of the tree and from different trees, to determine whether there was any significance in the relative abundance of the emergence of one generation and the number of subsequent attacks. This work was done with the idea that perhaps bark counts could be used to predict the course of an infestation.

DATA SECURED

The data upon which the present study is based were secured by a number of different observers working in various parts of southern Oregon and northern California.

Table 1 gives a summary of the bark counts secured in this work, which in the succeeding portion of this paper have been grouped in various ways to bring out the influence of different factors.

Average Attack and Emergence

On summarizing the bark counts from the 4,177 square feet of bark examined in the southern Oregon area, we find that the average attack per square foot is approximately 11 and the average emergence about 64. According to the deviations computed in the other tables, attack counts can be expected to have a standard deviation of about 6, while emergence counts have a standard deviation of about 50. Therefore not much reliance can be placed upon averages of these events unless they are based on sufficient data to overcome these great dispersions. On the basis of all the counts so far made we have a fairly good idea of the average or normal conditions in this

region. In general, since two beetles are required for each successful attack, about three beetles emerge for every one that attacks, and the potential increase is therefore 200 per cent. But a great mortality occurs in flight and such an increase is not often obtained, although at times it is exceeded.

Assuming then that 11 attacks and 64 exits per square foot represent normal conditions in standing trees, we can now examine the data to determine what factors cause a divergence from the normal and in what way these variations affect the progress of an infestation.

Variability of Counts

One of the first things to impress the workers in this field was the tremendous variation in emergence and other events during any one year among different trees, and even on any one tree in different parts of the tree. At once it became evident that no general rule could be deduced from an intensive study of a single tree or a small series of trees, and that valuable results were possible only through statistical methods involving data taken from a large series of trees on different areas, sites and slopes during a long period of years. Only by approaching the problem in this way would it be possible to isolate the effects of different factors and equate their magnitude and importance.

TABLE 1
SUMMARY OF BARK-COUNT DATA

Year of Attack	Locality: Area	Locality: Unit	Basis of Counts: No. Trees	Basis of Counts: Sq.Ft. Bark	Average Events of D. brevicomis: Attacks	Average Events of D. brevicomis: Emergence	Observers and Notes
1914	Rogue River	Lamb's Mine	4	15	-	96	Keen
1915	"	"	14	129	-	54	Keen; emergence from trap trees
	"	"	8	16	-	118	Keen; emergence from standing trees
	"	Ashland	7	11	-	61	Glendinning
	"	Frederick	4	9	-	84	"
1916	"	Lamb's Mine	11	60	-	74	Keen; standing trees
	"	"	5	45	5.5[1]	31	Keen; trap trees, [1]based on 24 sq.ft.
	"	Ashland-Frederick	63	119	-	51	Glendinning, Sergent
1917	"	"	27	111	-	59	Glend., Sergent, Wagner
	"	Mistletoe	6	52	7.3	35	" " "
	S.O.-N.C. Area 1	Jenny Creek	21	21	12.0	68	Sergent
1918	Rogue River	Wagner	32	144	-	66	Glend., Sergent, Wagner
	"	Ashland-Frederick	35	157	-	68	" " "
	"	Lamb's Mine	34	189	13.8[2]	44	" " [2]based on 54 sq.ft.
	"	Mistletoe	1	7	14.6	33	Sergent
	S.O.-N.C. Area 1	Jenny Creek	26	26	12.3	72	"
1919	Rogue River	Ashland	2	2	5.0	40	"
	S.O.-N.C. Area 1	Jenny Creek	26	26	12.4	60	" Patterson
1920	Rogue River	Ashland	44	44	15.2	38	"
	"	Frederick	5	30	6.5	31	"
	"	Lamb's	5	29	6.5	32	"
	S.O.-N.C. Area 1	Jenny Creek	51	68	10.9	51	" Patterson
1921	Rogue River	Ashland	26	26	13.9	70	"
	"	Lamb's Mine	2	8	-	29	"
	S.O.-N.C. Area 1	Jenny Creek	33	33	13.1	50	" Patterson
	" "	Clover	2	16	6.0	64	Buckhorn
	" Area 2	Shaver	3	24	6.2	91	"
	" "	Saddle Mountain	6	48	7.7	79	" Wise
	" "	Chiloquin	2	16	10.6	76	" "
1922	Rogue River	Ashland	41	41	12.7	47	Sergent
	"	Lamb's Mine	7	7	12.7	-	"
	S.O.-N.C. Area 1	Jenny Creek	[illegible]	66	[illegible]	[illegible]	" Patterson
	" "	Round Lake	[illegible]	80	[illegible]	94	Buckhorn and Wise
	" Area 2	Algoma	10	60	[illegible]	102	"
	" "	Shaver	5	38	6.0	93	" "
	" "	Saddle Mountain	4	32	9.9	168	" "
1923	"	Area 1: Jenny Creek	22	22	13.3	62	Sergent, Patterson
	"	Area 2: Algoma	1	8	11.2	64	Buckhorn, Wise
	"	" Saddle Mountain	2	16	10.6	158	" "
1924	"	Area 1: Jenny Creek	47	438	10.8	54	Patterson, Byrne, O'Neil
	"	Area 2: Swan	25	252	14.0	67	" " "
1925	"	Area 1: Jenny Creek	25	294	21.2	-	" " "
	"	" "	20	245	11.1	81	Buckhorn, Miller
	"	" Aspen Lake	10	20	14.2	98	"
	"	" Clover Station	10	20	13.5	84	"
	"	" Klamath Canyon	17	240	7.7	79	" Miller
	"	Area 2: Swan	4	44	12.6	-	Patterson
	"	" "	20	141	10.4	58	Buckhorn, Miller, Keen
	"	" Black Hills	5	28	10.7	74	" "
	"	" Sycan	20	52	7.8	43	" "
	"	Area 3: Merritt Creek	20	142	9.6	56	" "
1926	"	Area 1: Jenny Creek	63	364	11.0	48	Keen, Buckhorn, England, Sabine
	"	" Aspen Lake	10	20	14.9	103	Buckhorn
	"	" Clover	10	20	13.9	73	"
Total Basis			979	4,177			
Median Values					11.	64	
Average Values					11.6	63	
Modal Value (approx.)					11.	65	

Variations in Attacks

Dispersion in Attack Counts

On summarizing the attack counts from 3365 square feet of bark examined over various areas of southern Oregon and northern California, we find considerable dispersion (Table 2), ranging from one to 36 attacks per square foot, with a mean of about 11 attacks and a standard deviation of six attacks per square foot. The frequency distribution of these counts is shown in Figure 1. It will be noted from Table 2 and Figure 1 that 64 records equal or exceed the limits of three times the standard deviation, when according to the normal law of error we should expect to find only nine observations equaling or exceeding this limit when this amount of bark had been examined. These counts are not necessarily due to errors of observation, but are due to the fact that the records include several different years and several localities, and hence are not the result of simple sampling. However, in comparing the observed deviations with the normal curve of error we find there is no marked discrepancy between the observed and computed curves, and so the averages secured when a large amount of bark is examined are probably fairly reliable.

Considering the dispersion shown by the bark counts making up this large sample, in similar work we should expect a standard deviation of approximately six. If then we wish to obtain a sample giving a maximum error in the mean of plus or minus 1, the standard error must not exceed one-third of that, or $\pm .33$. Therefore the number of samples required are

$$n = \left(\frac{s}{S}\right)^2$$ where n = number of samples to be taken
s = standard deviation of any observation
S = standard error

$$n = \left(\frac{6}{.33}\right)^2 = 324$$

In other words, counts on 324 square feet of bark taken in the same manner as in the past should give an average attack per square foot having a maximum error of not more than plus or minus 1.

TABLE 2

Dispersion of Attack Counts

Attacks per sq.ft.	No.of Sample Sq.Ft. (n)	Deviation from Origin (11)		Product d^2n
		d+	d-	
1	26		10	2600
2	78		9	6318
3	127		8	8128
4	142		7	6958
5	168		6	6048
6	199		5	4975
7	240		4	3840
8	224		3	2106
9	252		2	1008
10	217		1	217
11	256	0	0	0
12	237	1		237
13	217	2		868
14	203	3		1827
15	141	4		2256
16	110	5		2750
17	108	6		3888
18	84	7		4116
19	47	8		3008
20	41	9		3321
21	40	10		4000
22	30	11		3630
23	29	12		4176
24	25	13		4225
25	9	14		1764
26	16	15		3600
27	17	16		4352
28	8	17		2312
29	17	18		5508
30	10	19		3610
31	11	20		4400
32	7	21		3087
33	1	22		484
34	12	23		6348
35	1	24		576
36	4	25		2500
37	0	26		
38	1	27		729
Total	3365			119770

Mean = 11

Standard deviation =

$$\sqrt{\frac{\Sigma d^2}{n}}$$

$$= \sqrt{\frac{119,770}{3365}}$$

= 5.96 or 6

Chance that a deviation will equal or exceed 3 times the standard deviation is

1 in 370

Calculated - 9

Observed - 64

Tree Characteristics

Attack counts vary on any one tree, due to a number of factors, some of the more obvious of which appear to be diameter of trees affected, height and exposure of attack on the bole, thickness of bark and rate of growth. The large series of records obtained during the last eleven years show to some extent the relative influence of these factors.

(a) Diameter of Trees Selected

In order to determine whether or not attacks varied with trees of different diameters, the bark counts were summarized in ten-inch diameter groups. The results are given in Table 3:

TABLE 3
Influence of Diameter upon Attacks

Diameter Groups (inches)	Average Attacks per sq. ft.	Basis (sq.ft.)	Standard Error
10-18	11.4	472	
20-28	11.1	1853	
30-38	10.8	771	.21
40-48	11.9	256	.39
50-over	8.4	13	
General Average	11.1	3365	

Since the average attacks between the 30-39-inch group and the 40-48-inch group show the greatest spread, it may be worth while to examine this difference to see whether or not it is significant:

Difference of Averages (30-38) and (40-48) = 11.9 - 10.8 = 1.1
Standard Deviation of Differences $(.39^2+.21^2)^{\frac{1}{2}} = (.152+.044)^{\frac{1}{2}} = .44$
Ratio $\frac{1.1}{.44} = 2.5$.

Therefore the data do not show any real difference between the averages of the different diameter groups. There may, however, be a slight tendency for fewer attacks per square foot to occur on trees of large diameter than on small-diameter trees, due to lower resistance of larger trees; but the data are so variable that this cannot be shown from the bark counts at hand.

(b) Different Heights on Bole

Comparing the average attacks per square foot by different ten-foot log lengths, the results given in Table 4 were secured:

TABLE 4
Influence of Height on Bole upon Attack

Height Above Ground	Average Attacks per sq.ft.	Basis (sq.ft.)	Standard Error
5 ft.	11.1	431	.25
15 "	11.6	423	.28
25 "	11.6	367	
35 "	11.7	313	
45 "	12.2	246	.41
55 "	11.8	189	
65 "	11.6	128	
75 "	11.3	71	
85 "	12.3	38	
95 "	14.7	28	1.43
Average	11.6	2234.	

A study of the above results indicates that there is a tendency of the beetles to attack more heavily through the middle trunk than at the top or bottom of the bole. This tendency, however, is very slight; and when we compare the difference in the averages between those showing the greatest spread (where the basis is at all adequate) we find that the greatest difference is between the attacks at the 5th and the 45th foot.

Difference in Average Attack (45th-5th) $12.2 - 11.1 = 1.1$
Standard Deviation of Differences $(.41^2+.25^2)^{\frac{1}{2}} = .48$
Ratio of Difference to Standard Deviation of Difference $\frac{1.1}{.48} = 2.3$

Since this ratio is less than 3 it cannot be said that the difference in the averages is significant. However, the ratio is large, so there may still be some real difference in the number of attacks at the top and base of the tree that cannot be definitely shown even with the counting of 2234 square feet of bark.

(c) Exposure on Bole

A large series of records was taken from different sides of the standing tree. When the attack counts were summarized as to north, south, east and west exposure the averages shown in Table 5 were secured:

TABLE 5
Influence of Exposure upon Attacks

Side of Trunk	Average Attacks per sq. ft.	Basis (sq. ft.)	Standard Error
North	8.7	845	.18
South	9.4	506	.21
East	8.9	616	.19
West	9.3	533	.21
General Average	9.0	2500	.10

These averages indicate that the heaviest attacks occur on the south side of the tree and the lightest attacks on the north. The next question that arises is whether or not these variations in averages are due to some real differences in selection by the beetles or simply to errors in sampling.

Comparing the standard deviation of the difference between any average with the difference in the averages, we find the following;

Between N and S sides

Difference in averages $9.4 - 8.7 = .7$

Standard deviation of difference $\sqrt{S_n^2 + S_s^2}$

$$= \sqrt{.21^2 + .18^2} = .276$$

Ratio $\frac{.7}{.276} = 2.54$

Therefore the difference is possibly of some significance.

Between E and W sides

Difference in averages $9.3 - 8.9 = .4$

Standard deviation of difference $(S_w^2 + S_e^2)^{\frac{1}{2}}$

$$= (.21^2 + .19^2)^{\frac{1}{2}} = .28$$

Ratio $\frac{.4}{.28} = 1.4$

Since the difference in averages between the east and west sides is much less than three times the standard deviation of the differences, there is no assurance that the difference has any significance.

Similarly it can be shown that the differences in attacks between the north side and east or west side are not great.

However, the stronger attack on the south side of the trees seems to be due to some cause other than mere chance. It may be due to the direction of the prevailing winds and beetle flight or to the influence of sunlight on the south side of the tree.

(d) Thickness of Bark

Comparing samples from 444 square feet of bark on thin-bark trees and 651 square feet on thick-bark trees, taken during a 13-year period in the southern Oregon-northern California region, we find the average attacks as shown in Table 6

TABLE 6
Influence of Bark Thickness upon Attack

Thickness of Bark	Average Attack per sq. ft.	Basis sq.ft	Standard Error
Thin	9.3	444	.25
Thick	12.9	651	.24

Difference of averages $12.9 - 9.3 = 3.6$
Standard deviation of differences $(.25^2 + .24^2)^{\frac{1}{2}} = .35$
Ratio $\frac{3.6}{.35} = 10.3$

Since the difference in the averages is over ten times the standard deviation of the differences, it is very decidedly significant.

Now the next question is why this should be so.

The only explanation that occurs to me is that thin-bark trees are usually the slow-growing ones that offer little resistance to barkbeetle attack, while the thick-bark trees are usually fast-growing and require a greater concentration of beetles to make a successful kill. Probably on such trees, if the average attack is less than 12 per square foot, the tree is able to drown out the invaders and resist the attack. This of course ties in with other evidence recently secured as to tree susceptibility.

Seasonal Fluctuations of Attacks

(a) Due to variations in amount of infestation

The longest series of continuous records of bark counts and infestation are to be had on the Jenny Creek Unit. This work, started by Patterson in 1917, was carried through to the present time and covers a period of ten years.

Fig. 2 shows the fluctuations in attacks during this period and the range of standard error of the counts, which of course varies with the amount of bark examined in the different years. Thus with 22 square feet examined in 1923 we have a standard error in the mean of $\pm.8$ attacks and a maximum error of 2.4 attacks; while in 1924, with 444 square feet counted, the standard error of the mean is $\pm.17$ and the maximum error $\pm.5$.

From an inspection of the graph in Fig. 2 it would appear that from 1918 to 1924 there was a negative correlation between attacks and infestation. That is, with a high number of attacks the infestation declined, while with a low number of attacks it was high. However, in 1925 this process was reversed, and the extremely high number of attacks developed a very high infestation, which was followed by a decline in both attacks and infestation.

There is no point in working out the correlation ratio of this set of data, since it is so evident that no general law holds and that intensity of attack is not important in determining the character of the succeeding infestation.

In general there is very little seasonal fluctuation in the average number of attacks per square foot. The beetles apparently know about how many attacks are needed to kill a tree, and that if they do not attack in sufficient numbers the tree will resist the invasion. Again, there is rarely any crowding of attacks. If beetles are plentiful they will extend their attacks to other trees rather than concentrate on a few.

The very heavy attack of 1925 is an exception to the general rule that is worthy of some consideration. In 1924 conditions were particularly favorable to beetle development, and a tremendous beetle population was built up. This resulted in a very heavy attack upon the trees in 1925 and also developed a tremendous increase in the number of trees attacked. Contrary to expectations, the heavy attack had no influehce in bringing about brood mortality, and the emergence from the 1925 trees was extremely heavy.

It is evident therefore that other factors beside the intensity of attacks are the dominant influences in producing a heavy or a light infestation.

(b) Due to influence of normal tree growth rate

On graphing normal tree growth rate with the strength of attack we find an apparent positive relationship, brought out in Fig. 3. This indicates that as the growth improves the number of beetles necessary to kill a tree increases, and as tree vigor declines it takes fewer beetles per square foot to bring about death.

According to the graph, this tendency appears to be very marked and entirely consistent. However, upon computing the coefficient of correlation from this set of data (see Table 7) we find the period of years covered by the records too short for definite conclusions.

TABLE 7

Correlation of Western Pine Beetle Attack and Tree Growth Rate From Seasonal Averages on Jenny Creek Plot

Year	Average Growth Rate in mm.	Average Number Attacks per sq.ft	xy	x		y	
	x	y		d	d^2	d	d^2
1917	.95	12.0	11.40	+.03	.0009	-.5	.25
1918	.96	12.3	11.81	+.04	.0016	-.2	.04
1919	.98	12.4	12.15	+.06	.0036	-.1	.01
1920	.94	10.9	10.25	+.02	.0004	-1.6	2.56
1921	1.09	13.1	14.28	+.17	.0289	+.6	.36
1922	.72	12.2	8.78	-.20	.0400	-.3	.09
1923	.98	13.3	13.03	+.06	.0036	+.8	.64
1924	.72	10.8	7.78	-.20	.0400	-1.7	2.89
1925	1.03	16.6	17.10	+.11	.0121	+4.1	16.81
1926	.78	11.0	8.58	-.14	.0196	-1.5	2.25
Total	9.15	124.6	115.16		.1507		25.90
Aver.	.92	12.5					

Coefficient of correlation $r = \frac{\Sigma xy - n\overline{x}\overline{y}}{ns_x s_y}$

$s_x = \sqrt{\frac{\Sigma d^2}{n-1}}$

$s_x = \sqrt{\frac{.1507}{9}}$

$= .13$

$s_y = \sqrt{\frac{25.90}{9}}$

$= 1.70$

$r = \frac{115.16 - 10x.92x12.5}{10x.13x1.70}$

$= \frac{115.16 - 115.00}{2.21} = \pm.072$

Standard deviation of r

$r_{xy} = \frac{1-r^2}{\sqrt{n}} = \frac{1-.072^2}{\sqrt{1.0}} = \pm .314$

Since limit of error may be three times standard deviation the coefficient of correlation might be anywhere between +1.0 and -.86. Thus there is need for a larger series of averages than merely ten.

This tendency, if proven, should be a most important one from the standpoint of predicting the course of beetle epidemics. Even though it takes only a few more beetles per square foot to overcome the resistance of trees in favorable-growth years, the reduction in beetle population should be considerable. For instance, if the average number of attacks required to kill a tree were raised from 12 per square foot to 14 per square foot, 16.6 per cent of the beetle population would be used in this increased effort, and the infestation be less to this extent than it would otherwise have been. However, tree vigor is only one of the factors operative in controlling infestation. The emergence and beetle population must be taken into account; for it sometimes happens, as in 1925, that large beetle population can completely overshadow increased tree vigor and cause an increase in infestation. Neither does slow tree growth necessarily mean high infestation, for the beetle population may be too low to cause many attacks.

Therefore tree growth is only one of the factors that should be taken into account in predicting the course of barkbeetle infestations.

Variations in Emergence

So far we have considered only the variations in attacks, which do not have a very great spread. Nearly all the counts fall between 1 and 40 attacks per square foot, with a fairly consistent mean around 9 to 12 per square foot. However, when we examine the counts of emergence we find a tremendous spread, with counts ranging anywhere from 0 to 340 per square foot, and with very little tendency for the counts to group around any particular figure. At once it becomes apparent that in order to secure averages that mean anything at all a tremendous amount of bark must be examined.

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From a single tree

At Northfork, Calif., in 1923, a 56-inch d.b.h. tree 130 feet in length, killed by the western pine beetle in the fall of 1922, was felled and bark counts of a large part of the bark surface made under the direction of Mr. J.M. Miller. Altogether emergence counts were taken on 125 square feet.

The range, as with all emergence counts, was tremendous, varying from 30 to 235 per square foot with no well-defined central tendency. The standard deviation was 36 and the standard error 3.2.

On this basis, in order to secure a mean emergence from a single tree with a maximum error of ±1 it would require the examination of "n" samples where $n = \left(\frac{s}{S}\right)^2 = \left(\frac{36}{.33}\right)^2 = 11{,}900$ square feet of bark, which is over 15 times as much bark as there was on this tree

If all the infested bark on this tree, consisting of 753 square feet, had been examined, the same or greater standard deviation could have been expected, in which case the standard error would have been $S = \frac{36}{(753)^{\frac{1}{2}}} = 1.3$, and the maximum error of the mean would have been $3xS = 4$. In other words, even if all the bark had been examined, the average emergence figure would still be subject to a maximum error of 4 beetles per square foot. Similarly, the examination of all the bark on a ten-foot log in the middle trunk would be subject to a maximum error of 11 beetles per square foot.

Thus it is very evident that great caution should be exercised in using emergence figures to prove any particular tendencies on the part of the beetles to be influenced by various factors, and that the complete examination of any one tree will not give sufficiently reliable evidence from which to draw any conclusions.

From a large series of trees

In Fig. 4 the emergence counts from 2680 square feet of bark are grouped in a frequency polygon. The range is from 1 to 341, the mean 64 and the median 54. There is no well-defined mode, but a slight tendency toward grouping between 40 and 50; the standard deviation is found to be 50. With such an immense variation and little or no prpnounced central tendency, the averages have almost no significance.

If the counts do follow any law whatever, in order to bring the maximum error of the mean within ±1, the standard error will have to be one-third of this, or .33. The number of samples required would then be $n = \left(\frac{s}{S}\right)^2 = \left(\frac{50}{.33}\right)^2 = 22{,}500$ square feet of bark, which is over five times the amount of bark that has been examined in the last 11 years.

In other words, all the emergence counting which has been done means practically nothing, and could not mean anything without the investment of an unreasonable amount of time and money. Even then there is no assurance that the results would be of any value.

Bearing in mind the absolute unreliability of any of the emergence counts, it may be of interest to examine the data we now have to see if they are even suggestive.

Influence of Tree Characteristics

We might expect the emergence counts to vary with trees of different sizes, at different heights and exposures on the bole and with bark thickness. On summarizing the counts in these different ways the following results were secured:

(a) Diameter

In tabulating all the records on the southern Oregon region by tree diameter classes we find the following variations in emergence:

TABLE 8
Influence of Tree Diameters upon Emergence

Tree Diameters	Average Emergence per sq.ft.	Basis sq. ft.	Approximate Standard Error
10-18"	60	484	2.2
20-28"	57	1775	1.2
30-38"	69	888	1.7
40-48"	71	257	3.1
50-58"	75	14	13.4

There appears to be a slight tendency for the larger trees to develop stronger broods than the smaller ones. However, when we submit these averages to analysis we find:

Difference in averages (50-58) and (10-18) 75-60=15
Standard deviation of differences $(13.4^2+2.2^2)^{\frac{1}{2}}=13.6$
Ratio $\frac{15}{13.6} = 1.1$

which indicates no significance to difference in these averages.

However, between (40-48) and (20-28) we find

Difference 71-57=14
Standard deviation of differences $(3.1^2-1.2^2)^{\frac{1}{2}}=3.3$
Ratio $\frac{14}{3.3} =4.2$

This would indicate that where the records are sufficient some real difference may be found in emergence between the large and the small trees. Why this should be so is difficult to explain.

(b) Height on bole

During 1924 and 1925 an extensive series of records was taken in the southern Oregon region at different heights on the boles of the attacked trees. Each infested tree was felled and a sample, consisting of two square feet of bark, was examined on every ten-foot log. The results of these two years of bark counts gave the following averages:

TABLE 9
Influence of Height on Bole Upon Emergence

Height of Log from Ground	Aver. Attacks per sq.ft.	Aver. Emergence per sq.ft.	Basis sq.ft.	Standard Error of Emergence	Ratio of emerging to Attacking Beetles
5'	11.1	54	411	2.4	2.4
15	11.6	60	409	2.6	2.6
25	11.6	62	358	2.7	2.7
35	11.7	62	311	2.6	2.6
45	12.2	69	200	3.2	2.8
55	11.8	57	147	3.6	2.4
65	11.6	62	95	4.6	2.7
75	11.3	76	48	7.1	3.4

It is very evident that attacks per square foot and emergence is in general almost uniform throughout the length of the infested trunk, and for the most part the apparent variations can be accounted for as errors in sampling.

There is a tendency for the attacks to be heaviest in the middle trunk. This seems reasonable, since the overpowering of a tree is usually accomplished by the beetles first attacking the middle portion of the trunk and then extending their attacks both up and down the trunk. Some trees are attacked from the top down and a few from the bottom up; but the majority are attacked in the middle, and the subsequent attacks occur both above and below the first center of onslaught. The emergence at different heights on the bole appears to be nearly constant and not affected by position as to height alone. The only exception is the basal log, where in general emergence falls below normal, due undoubtedly to the usual excessive-moisture conditions near the base of the tree.

Comparing the extreme differences in emergence at top and bottom we find the following:

Significance of difference in average emergence at top and bottom of trunk

From the averages given in Table 9 we find that the highest emergence per square foot occurred at 75 feet from the ground and the lowest at 5 feet from the ground.

Difference in averages 76-54=22
Standard deviation of difference $(7.1^2+2.4^2)^{\frac{1}{2}} = 7.5$
Ratio $\frac{22}{7.5} = 2.9$

Since the ratio is less than three, the difference in emergence can hardly be said to be of much significance.

Considering the difference between the base and middle sections, we find:

Diff. in averages bet. 5-ft. height and 45-ft. height 69-54=15
Standard deviation of difference $(3.2^2+2.4^2)^{\frac{1}{2}} = 4.0$
Ratio $\frac{15}{4} = 3.7$

Therefore the heavier emergence in the middle trunk than in the basal portion appears to be a significant difference and not due simply to errors in sampling. Usually the basal portion of the trunk is too moist for good brood development, which would account for the difference. The varying emergence above the first log, however, has little significance.

(c) Height and Diameter

On the Jenny Creek Unit of the Southern Oregon Project, records were taken on the 1924 logs to show the attacks and emergence at different heights on the bole for different diameters. The results are shown in Fig. 5, which brings out some very interesting points. In general the tendency is the same as was brought out in the summary of the two years of records. The basal log shows a comparatively low emergence, but emergence from the upper part of the trunk is practically uniform.

(d) Exposure on Bole

To determine what influence exposure on the bole may have on brood development and subsequent emergence, the data have been arranged and summarized accordingly. Taking the data for all years and from all localities the averages shown in Table 10 were secured.

TABLE 10

Exposure on Bole	Average Emergence per sq.ft.	Basis sq. ft.	Standard Error
North	58	761	1.9
South	73	630	2.1
East	65	662	1.8
West	62	627	1.8
General Average	64	2680	1.0

Thus the emergence tendencies in general are the same as those for attacks--heaviest on the south side, lightest on the north, and intermediate on the east and west sides of the bole.

The next question is whether or not these averages are accurate enough to be significant.

Between the north and south sides:

Difference in averages 73-58=15
Standard deviation of differences $(S_s^2+S_n^2)^{\frac{1}{2}}$
$=(2.1^2+1.9^2)^{\frac{1}{2}}$
$=2.83$

Ratio $\frac{15}{2.83} = 5.3$

Since the difference in the averages is more than five times the standard deviation of the differences, the differences in emergence between the north and south sides of the trees is very probably of some significance.

One reason for this may be that the attack is heaviest on the south and lightest on the north. On comparing, then, the ratios of attack and emergence on the different sides of the tree,

TABLE 11
Comparison of Attacks and Emergence

Side of Tree	Aver. Attacks per sq. ft.	Aver. Emergence per sq. ft.	Ratio: Emergence per Attack
North	8.7	58	6.7
South	9.4	73	7.8
East	8.9	65	7.3
West	9.3	62	6.7

it is evident that the broods do best on the south side of the tree and produce about one beetle more per attack than on the north side of the tree. Therefore conditions on the south must be more favorable for development than on the north, which would indicate that a certain amount of heat and dryness is favorable to the development of this barkbeetle.

While these figures represent the usual case, and are perhaps indicative of some general tendency, it should be borne in mind that seasonal differences may change conditions. Thus in very dry, hot years the north side of the tree may offer more ideal conditions for brood development than the south side, and cold, wet years may favor the south side.

(c) Thickness of Bark

The records summarized from thick- and thin-bark trees gave the emergence averages shown in Table 12.

TABLE 12
Influence of Bark Thickness upon Emergence

Bark Thickness	Aver. Emergence per sq.ft.	Basis sq. ft.	Standard Error
Thick	62	832	1.6
Thin	64	502	2.5

Difference in averages 64-62=2
Standard deviation of differences $(1.6^2+2.5^2)^{\frac{1}{2}} = 3$
Ratio $\frac{2}{3} = .66$

which shows rather conclusively that thickness of bark is not a factor influencing the emergence. The previous analysis of attacks showed very definitely that bark thickness, presumably as an index of tree vigor, had a very pronounced influence upon attacks; but that after the attack had been successfully made it no longer is a factor, and the subsequent development of the broods is influenced by other more important conditions.

(f) Influence of Attack Upon Emergence

Theoretically the number of beetles emerging from a tree should depend upon the number making the attack and factors affecting the development of the broods, such as bark temperature, bark moisture, parasites, predators, robbers, abundance of predatory birds, fungus disease, climatic conditions, nature of the food supply, and possibly other factors of which nothing is known at present.

In all the bark counts that have thus far been taken in the study of western pine beetle infestations, number of attacks is the only one of the above factors that has been measured, and hence is the only one that we can correlate with emergence.

In Fig. 6 is plotted the average number of beetles attacking and emerging on the Jenny Creek Unit from 1917 to 1926 inclusive. This graph indicates that, to some extent at least, the emergence is influenced by the number of beetles attacking—a low attack producing a low emergence and vice versa. These records do not indicate that overcrowding of attacks, such as occurred in 1925, is detrimental to good brood development.

On correlating the average attack and emergence counts from all samples taken on the Jenny Creek Unit, we find that the coefficient of correlation is +o.386±0.08, which with even the maximum error of three times the standard error leaves a positive correlation of from +0.62 to ± 0.14. This proves rather conclusively that the number of attacks do have an effect upon the emergence, and make up about 40 per cent of the total influence. It also becomes evident that the other factors mentioned above which were not measured are of greater importance than the number of attacks, and make up 60 per cent or more of the total influence.

However, an inspection of the graph (Fig. 6) shows that the ratio of attack and emergence is fairly constant. About so many beetles attack per square foot and about so many emerge each year without any tremendous fluctuation. The infestation that has developed from such attacks and emergence, however, has varied within a wide range. Therefore it hardly looks as though we could expect bark counts to give us an index to infestation.

Seasonal Fluctuations in Emergence

One of the first objectives of bark analysis was to secure an index to developing infestations through a count of the previous generation's emergence. Now that we have ten years of infestation and bark-count records on the Jenny Creek Unit let us see what they show.

(a) Relative Development of Summer and Winter Broods

To determine whether there is any consistent difference in the success of brood development between the summer and winter generations, the data on the Jenny Creek Area from 1924 to 1926 were summarized by generations.

The following ratios of number of emerging beetles for each one attacking were secured;

		Ratio
1924	Summer	2.4
	Winter	2.2
1925	Summer	4.1
	Winter	3.7
1926	Summer	2.0
	Winter	3.4
Aver. Ratio		2.75

It at once becomes apparent that there is no consistent difference between summer and winter generations in success of beetle development, but that each generation varies according to seasonal factors.

During these three years, in general, for every 100 beetles attacking, 275 beetles emerged. In each generation there was an increase in the new beetle population varying from 100% to 310% increase, yet during this period the infestation both increased and decreased, indicating that factors other than beetle population were the responsible causes.

(b) Relation of Emergence to Subsequent Infestation

Figure 7 shows the plotting by years of the average emergence per square foot and the proportion of stand killed. It at once becomes apparent that the average emergence showed a very small range of fluctuation, varying from 48 to 87 beetles per square foot. With the small amount of bark examined in the first few years we find that the standard error is large, running around 10. If we draw a horizontal line through 57, we find that this comes within the limits of the standard error for every year except 1918, 1925 and 1926; or in other words the records show no important variations in emergence except for these three years.

In studying these three years we find that contrary to expectations the emergence gives no clue to what is going to happen, but simply falls in line with what has already happened. For instance, the low emergence in 1924 in no way presaged the tremendous infestation that developed in 1925; nor did the enormous beetle population which was turned out from the trees in 1925 give a clue to the decline that followed in 1926.

From analogy, then, what can one say will be the infestation of 1927 (since the emergence in 1926 was low)? Apparently there is no clue.

So far the records in Dendroctonus brevicomis infestations show simply that the same factors that bring about a high percentage of trees killed also cause a high emergence from such trees, but that high emergence does not necessarily mean a high subsequent infestation. In this respect at least the results coincide with those secured by the writer in a study of the Dendroctonus ponderosae epidemics on the Kaibab and with Gibson's results in studying the Dendroctonus monticolae infestations of ~~Idaho and Montana~~. In all these cases aggressive infestations produced abundant broods, while endemic infestations and those in old centers of infestation turned out small broods.

This is perhaps a revolutionary point, because it means that the rise and fall of infestations depends less upon fluctuations in beetle population than upon other little-known factors, and so far all our control work has been directed toward reducing beetle population. Apparently there are always enough beetles present on an area to produce an epidemic if the conditions (as yet largely unknown) are right; and if conditions are not favorable an epidemic will fail in spite of a large beetle population. If this point is true--that beetle population is of little importance--then all our control work has been directed against a factor of minor importance, and the varying results secured from control work in the past can be easily understood. Since hundreds of thousands of dollars have already been spent in control work, and even greater expenditures may be made in the future, it is certainly urgent that the relative importance of beetle population as a factor in epidemics should be definitely determined.

(c) Correlation Between Beetle Population and Epidemics

The bark counts that were made on the Jenny Creek trees killed between 1917 and 1923 were made on from 21 to 66 square feet of bark each year. This amount of bark counting gave minor fluctuations in averages which have no significance, due to the small amount of bark examined. The records from 1924 to 1926 were made on from 255 to 438 square feet, which gave fairly reliable averages. During these years the 1924 trees turned out a normal emergence, which not only produced an extremely high number of attacks on the following generation trees, but killed a tremendous number of them. The concentrated attacks of 1925 produced healthy broods and turned out a tremendous beetle population, which in turn attacked the next season's trees lightly and killed only a relatively few of them.

These few records would indicate that if there is any correlation between beetle population and subsequent infestation it is a negative one; i.e. that large beetle populations produce low infestations and low beetle populations high infestations.

These Jenny Creek records are not the only ones that give this negative correlation, as witness the sudden increase on the California Forest in 1922 from a very low population, and the sudden decline in the infestation when the population had been built up. Again, on the San Joaquin Project, after the Chiquito Basin had been thoroughly cleaned in 1923 and the beetle population reduced almost to zero, the infestation of 1924 suddenly developed immense proportions. No matter what the emergence from the 1923 trees was, there were so few of them that the beetle population must have been very low.

However, there are other cases where high beetle population has been followed by an increase in infestation. The infestation on the Modoc in 1925, 1926 and 1927 is a case in point. Each year the beetle population doubled, and so did the infestation.

We do know, however, that epidemics cannot spring from nothingness, and a nucleus of beetles must be present on an area to act as the progenitors of the developing broods. We also feel reasonably sure, other things being equal, that control work has had its influence in reducing the quantity of infestation that would otherwise have developed on an area. The discouraging thing has been that after the losses have been reduced by control, favorable conditions in the following year may at times give such a high percentage of success to the few broods that escaped death in the control that the effects of the work are quickly nullified.

I therefore cannot help but conclude that there are always enough beetles present on an area to produce an epidemic if the right conditions develop, and that beetle population is of less importance than other unknown factors. A study, then, of brood development within the tree and emergence will lead us nowhere. We must revise our entire viewpoint and start a search for those factors that are of the greatest importance in causing the rise and fall of epidemics, and are entirely outside of anything studied so far.

Susceptible trees, slow-growing trees, climatic influences as affecting tree growth are not the answers, as we frequently have plenty of susceptible and slow-growing trees but do not necessarily have barkbeetle epidemics.

It looks as though it was a combination of climatic factors affecting the beetles themselves and at the same time their hosts. Instead of spending any more time on bark counts we should study the rise and fall of epidemics, and correlate these with weather and other conditions in a number of localities.

Influences Affecting Mortality in Flight

In the foregoing paragraphs we have found that the fluctuations in brood development within the tree are of small magnitude and apparently of little importance in the rise and fall of epidemics. The factors which are operative during the flight period appear then to be the ones of greatest importance and deserve our attention.

Unfortunately we have no accurate way of measuring flight mortality. We do not know how many trees are attacked by beetles and are able to resist attack. About the best we can do is to compare the relative abundance of emerging beetles with those that make successful attacks, and in this way secure some measure of those lost in flight.

In Table 13 an index to flight mortality has been computed. The average emergence per square foot from the old trees has been multiplied by the relative abundance of such trees to secure an index to the total emerging beetle population. In the same way the new attacks per square foot have been multiplied by the amount of infestation developing to secure an index to the abundance of attacks. The difference between those emerging and those attacking represent the amount lost in flight. The ratio of those lost to those making successful attacks is given in the last column and graphed in Fig. 9.

This indicates that the flight period (June, July, August and September) was very unfavorable to successful attack in 1923 and 1926, but was favorable for attacks in 1921 and 1925. Unfortunately we do not know the outstanding climatic differences between these years, which might account for the difference in success of attacks.

Before we can say which factors are of importance during the flight period, very complete records must be taken during such periods over a number of years and in different localities. These data should include complete meteorological records, tree-growth records, and records as to the abundance of enemies, including parasites, predators, birds etc. Until this is done we shall have no knowledge as to the most important factors that influence barkbeetle abundance and bring about the rise and fall of epidemics.

TABLE 13
An Index to Flight Mortality
Jenny Creek Unit

Flight Season of	(a) Emergence fm. old trees per sq.ft.	(b) % Stand Killed (Old Trees)	(c) Index to Total Emerging Population c=axb	(d) Attacks per sq. ft. on New Trees	(e) % of Stand Killed, New Trees	(f) Index total Beetle Population Absorbed in Attack f=dxe	(g) Index to Flight Mortality $g=\frac{c-f}{f}$
1918	68	.50	34	12.3	.61	7	3.9
1919	72	.61	43	12.4	.69	9	3.8
1920	60	.69	41	10.9	1.06	10	3.1
1921	51	1.06	47	13.0	.91	12	2.9
1922	50	.91	45	12.2	.90	10	3.5
1923	57	.90	46	12.8	.70	9	4.1
[illegible]	62	.70	43	10.7	.90	10	[illegible]
1925	54	.90	[illegible]	14.7	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	12.7

SUMMARY

Since 1916, in southern Oregon and northern California, over 4000 square feet of bark infested by the western pine beetle (Dendroctonus brevicomis Lec.) have been examined and the number of entrance and exit holes counted. The evidence secured from all this work points to the following conclusions:

Attack and emergence counts show great variability, and a great deal of bark must be examined before averages are at all significant.

Attacks range from 1 to 40 per square foot, with a mean usually falling between 6 and 12. It requires the examination of about 324 square feet of bark to secure an average attack figure which is accurate within ±1.

The attack counts indicate that:

(1) Attacks are heavier on thick-bark trees than on thin ones.
(2) There is about a 40% dependence of quantity of emergence upon quantity of attack.
(3) Attacks are heavier on the south side of the tree than on the north.
(4) There is a slight tendency for the attacks to be lighter in trees of large diameter (presumably of slow growth) than on small-diameter trees.
(5) There is some tendency for the beetles to attack more heavily in the middle trunk than at the base of trees.
(6) There appears to be no relation between quantity of attack per square foot and quantity of infestation that develops.
(7) There appears to be a tendency for attacks to fluctuate with tree growth, but the data on this point are not conclusive.

The emergence counts show a tremendous variation, with a range from 0 to 340 beetles emerging per square foot and with no central tendency or mode. It is impossible to secure a significant average emergence from a single tree with a maximum error of less than four beetles per square foot, even if all the bark were examined. In order to secure an average emergence with a maximum error of ±1, 22,500 square feet of bark would have to be examined.

Such emergence counts as have been made prove nothing, but at least indicate the following:

(1) That emergence in general is slightly heavier on the south side of trees than on the north.
(2) That large trees tend to produce heavier broods (per square foot) than small ones.

(3) That emergence does not vary due to height on the trunk, except that the basal log usually produces a smaller brood than the others.

(4) That there is no relation between emergence per square foot and subsequent infestation.

This study indicates that the small fluctuations in attack, brood development and emergence with individual trees during different years have little or no significance in accounting for the rise and fall of epidemics. Instead, the important factors appear to be operative during the flight period--after the beetles leave the trees and before they make a successful attack upon their new hosts.

Therefore our future studies should be concentrated upon determining the important factors that operate during the flight period and their relative importance.

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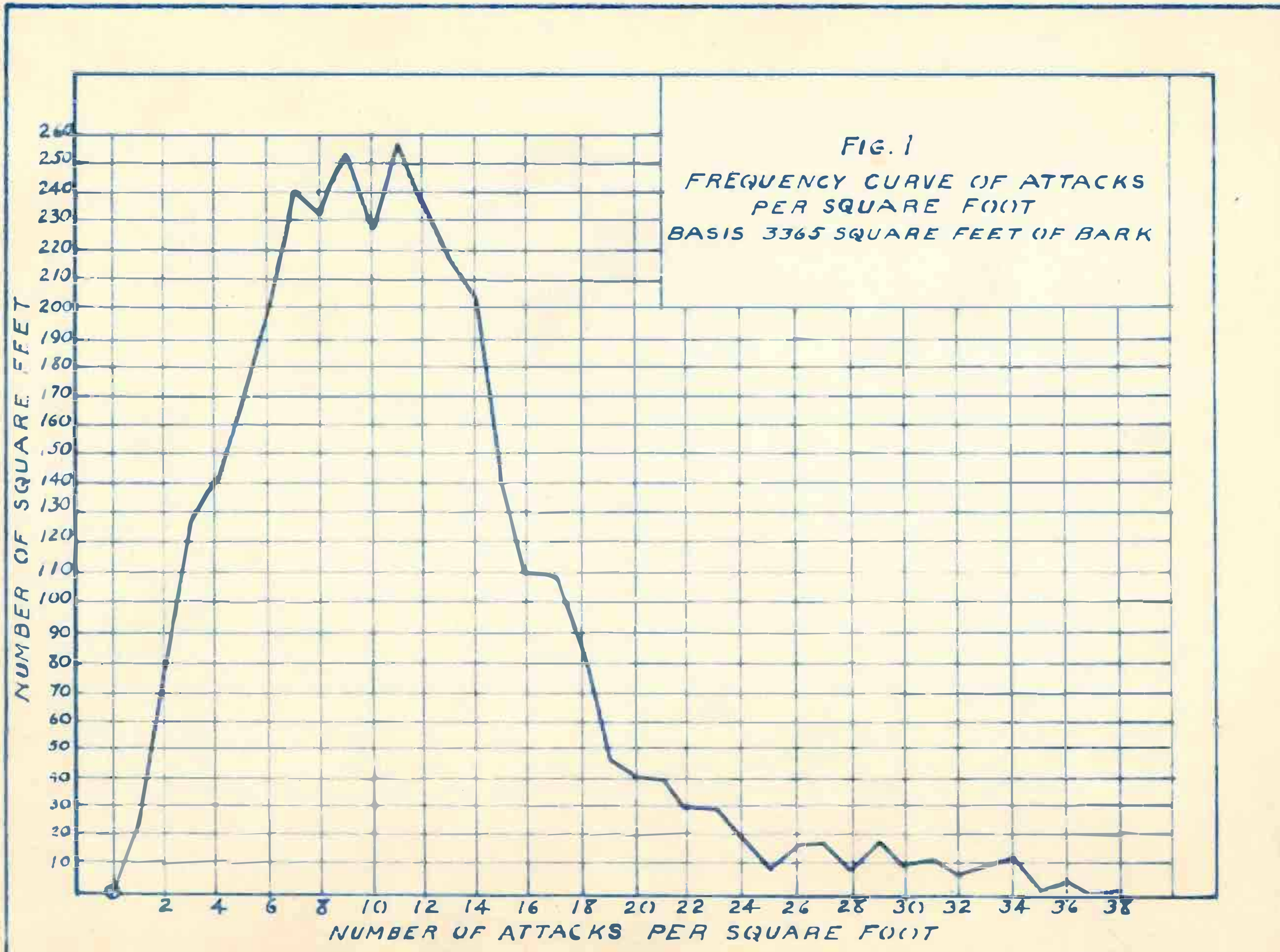
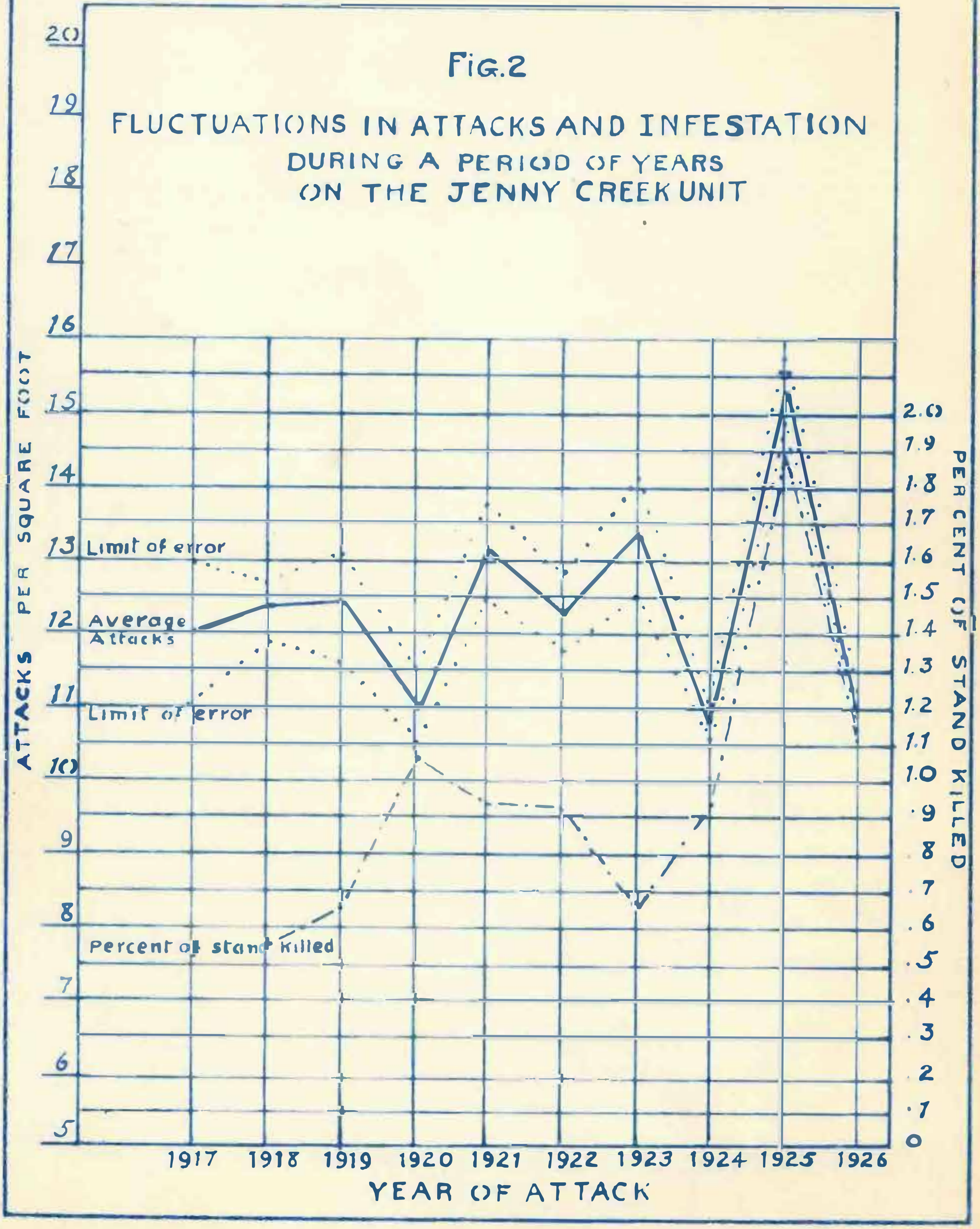


FIG. 1
FREQUENCY CURVE OF ATTACKS
PER SQUARE FOOT
BASIS 3365 SQUARE FEET OF BARK
NUMBER OF SQUARE FEET
NUMBER OF ATTACKS PER SQUARE FOOT
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38

FIG. 2

FLUCTUATIONS IN ATTACKS AND INFESTATION DURING A PERIOD OF YEARS ON THE JENNY CREEK UNIT



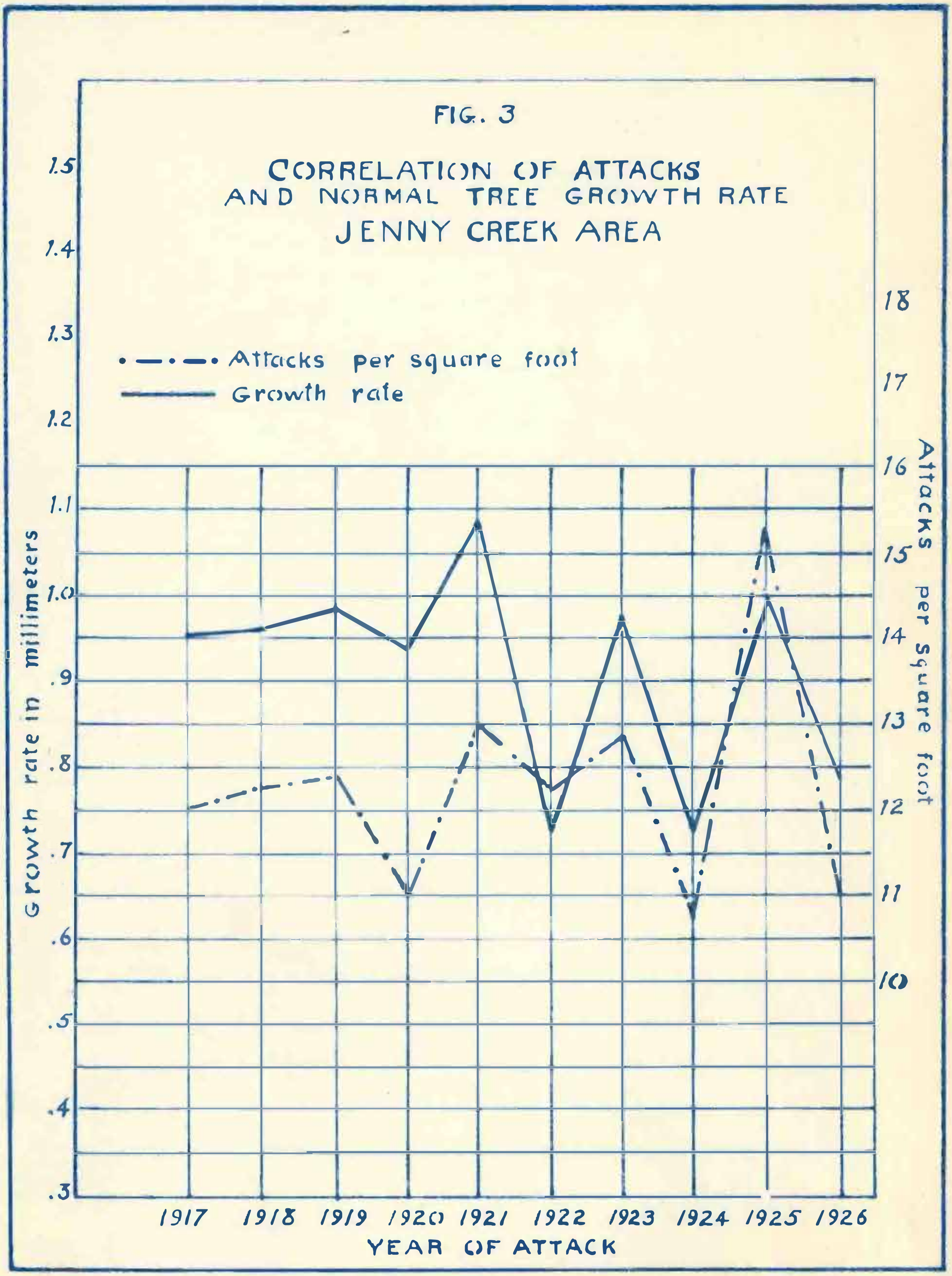


FIG. 3
CORRELATION OF ATTACKS
AND NORMAL TREE GROWTH RATE
JENNY CREEK AREA
Attacks per square foot
Growth rate
Growth rate in millimeters
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
Attacks per square foot
18
17
16
15
14
13
12
11
10
1917 1918 1919 1920 1921 1922 1923 1924 1925 1926
YEAR OF ATTACK

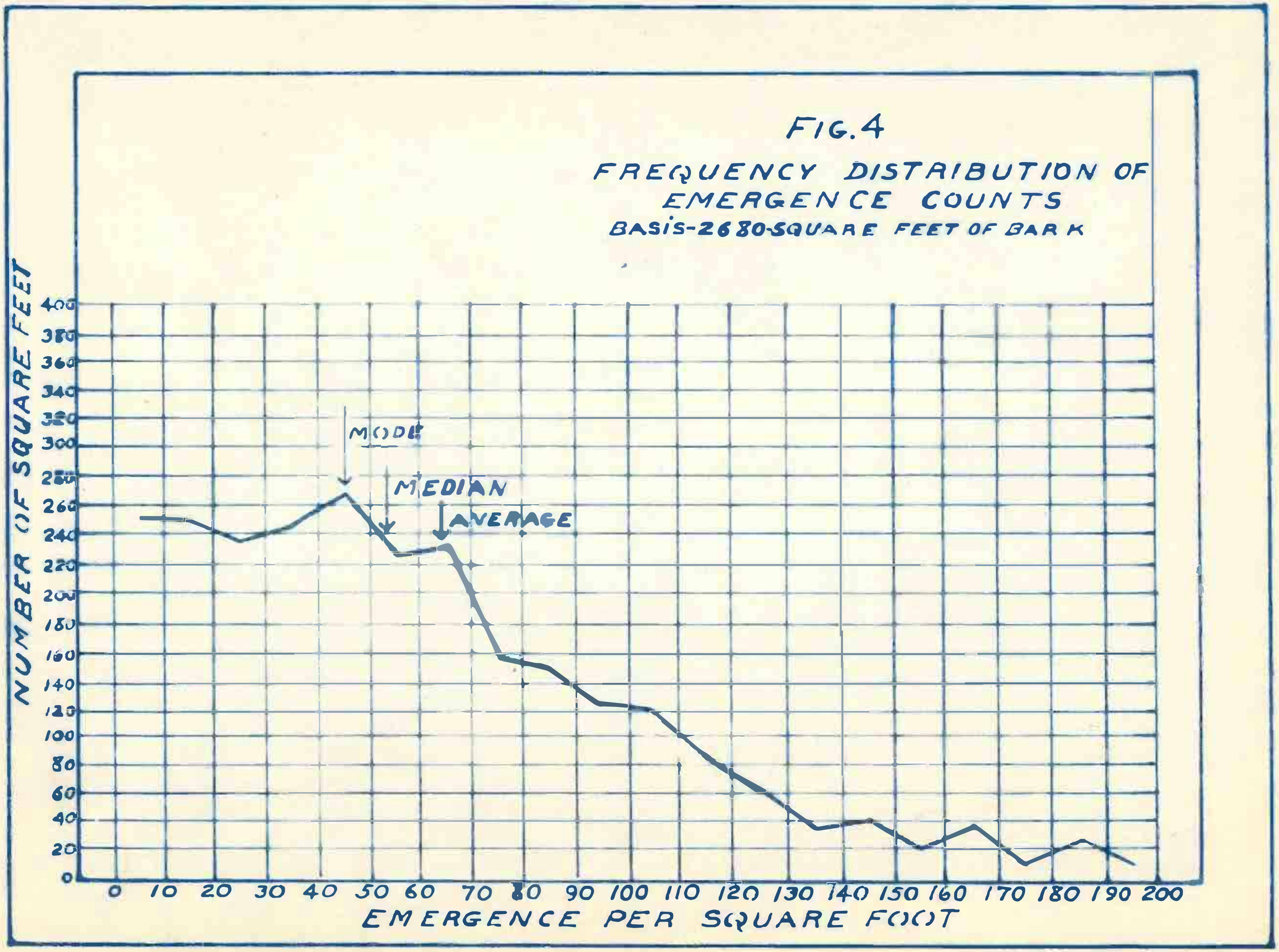


FIG. 4
FREQUENCY DISTRIBUTION OF EMERGENCE COUNTS
BASIS-2680-SQUARE FEET OF BARK
NUMBER OF SQUARE FEET
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
MODE
MEDIAN
AVERAGE
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
EMERGENCE PER SQUARE FOOT

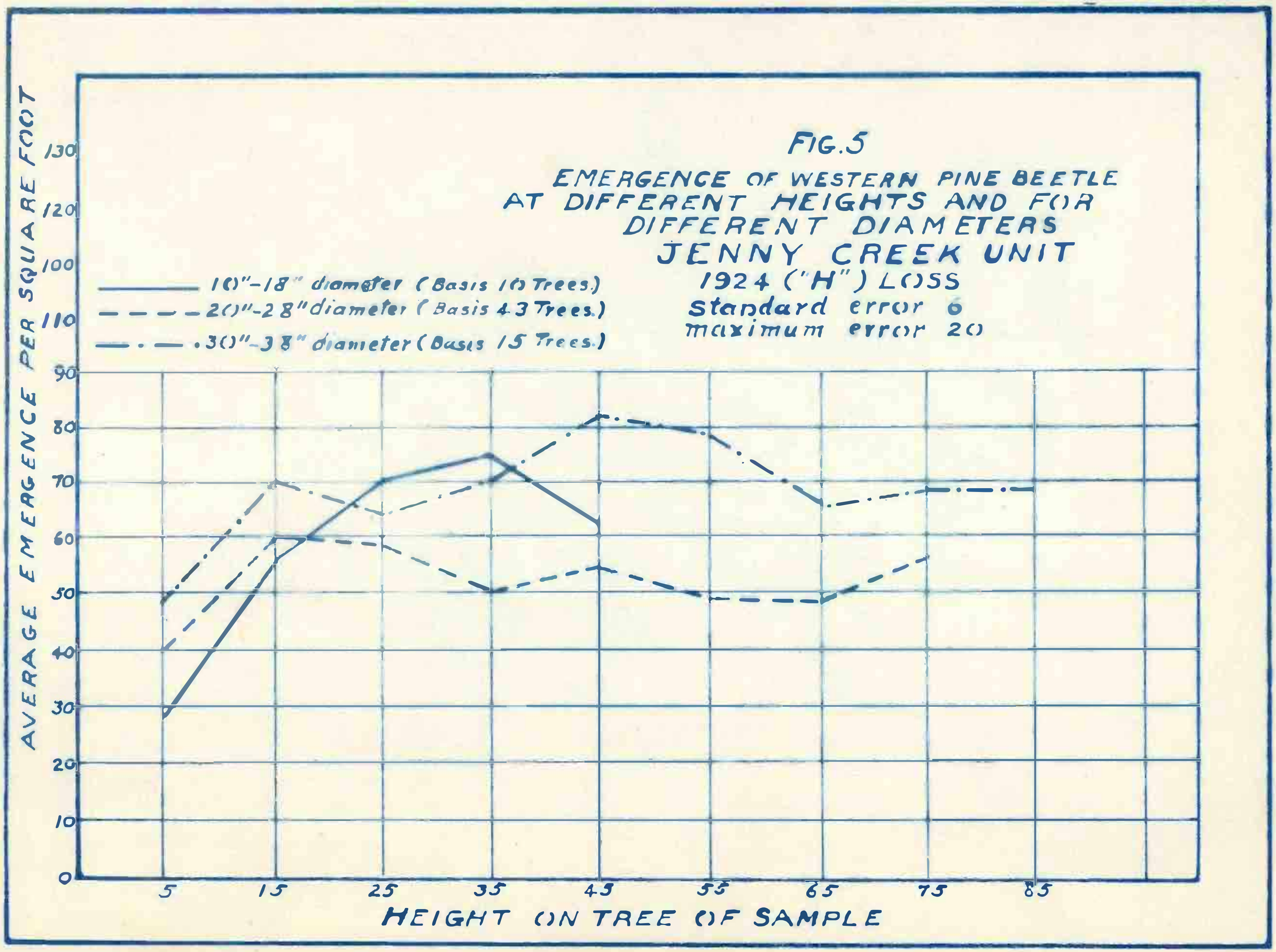


FIG. 5
EMERGENCE OF WESTERN PINE BEETLE
AT DIFFERENT HEIGHTS AND FOR
DIFFERENT DIAMETERS
JENNY CREEK UNIT
1924 ("H") LOSS
standard error 6
maximum error 20
10"-18" diameter (Basis 10 Trees.)
20"-28" diameter (Basis 43 Trees.)
30"-38" diameter (Basis 15 Trees.)
AVERAGE EMERGENCE PER SQUARE FOOT
0
10
20
30
40
50
60
70
80
90
110
100
120
130
5
15
25
35
45
55
65
75
85
HEIGHT ON TREE OF SAMPLE

233

FIG. 6

COMPARISON OF ATTACKS AND EMERGENCE

JENNY CREEK UNIT

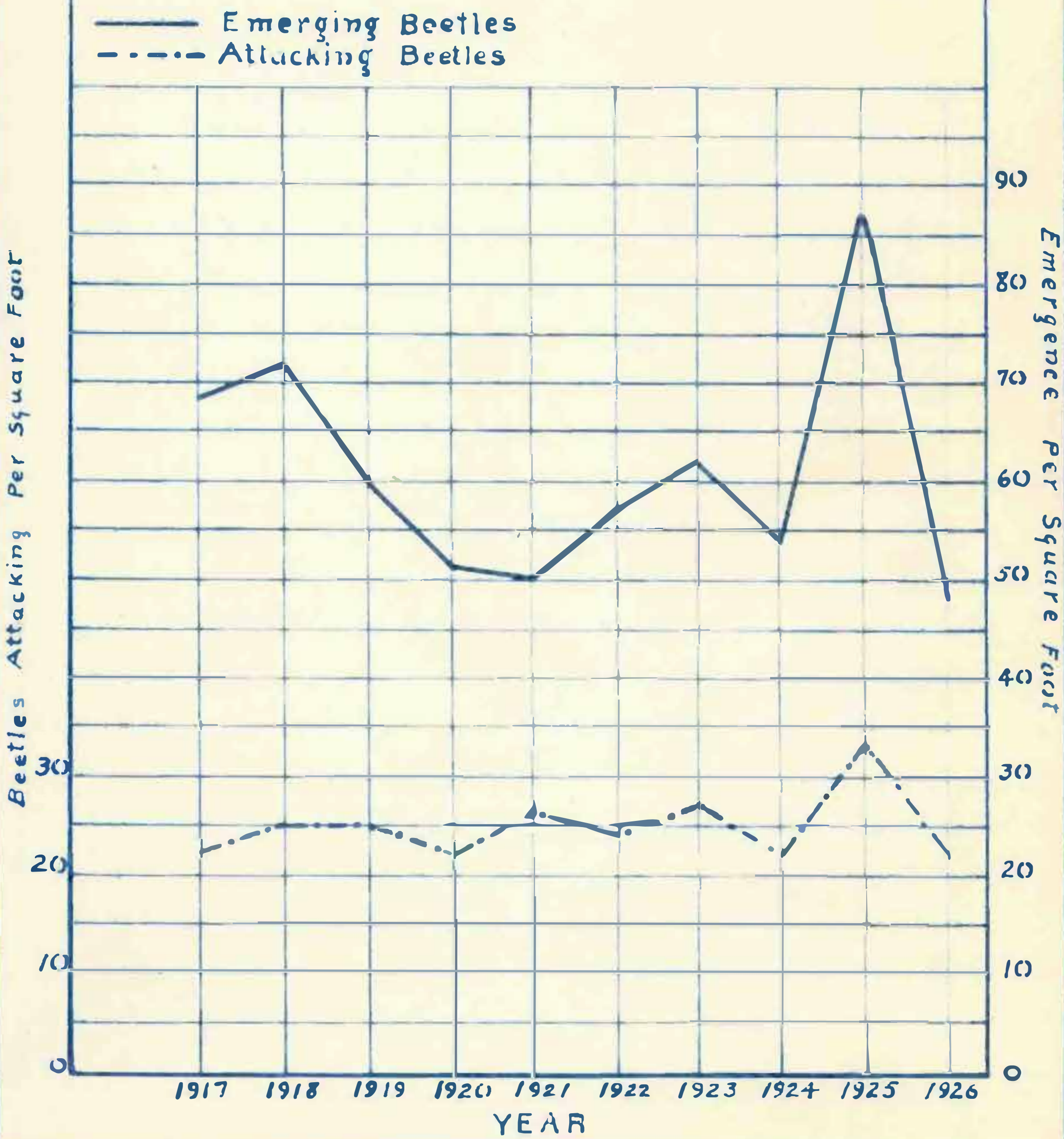
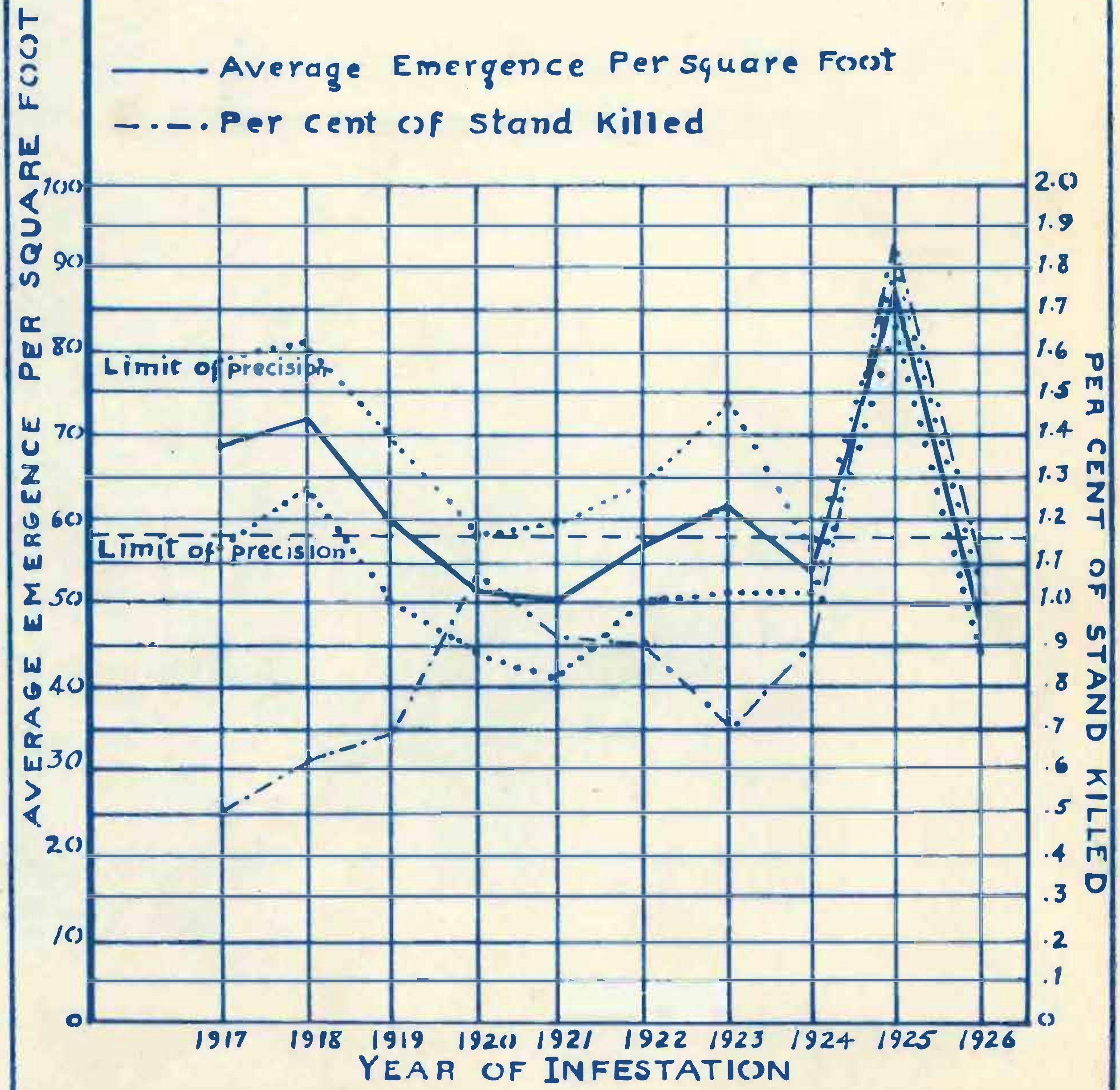


FIG. 7

COMPARISON OF EMERGENCE AND TOTAL INFESTATION JENNY CREEK UNIT



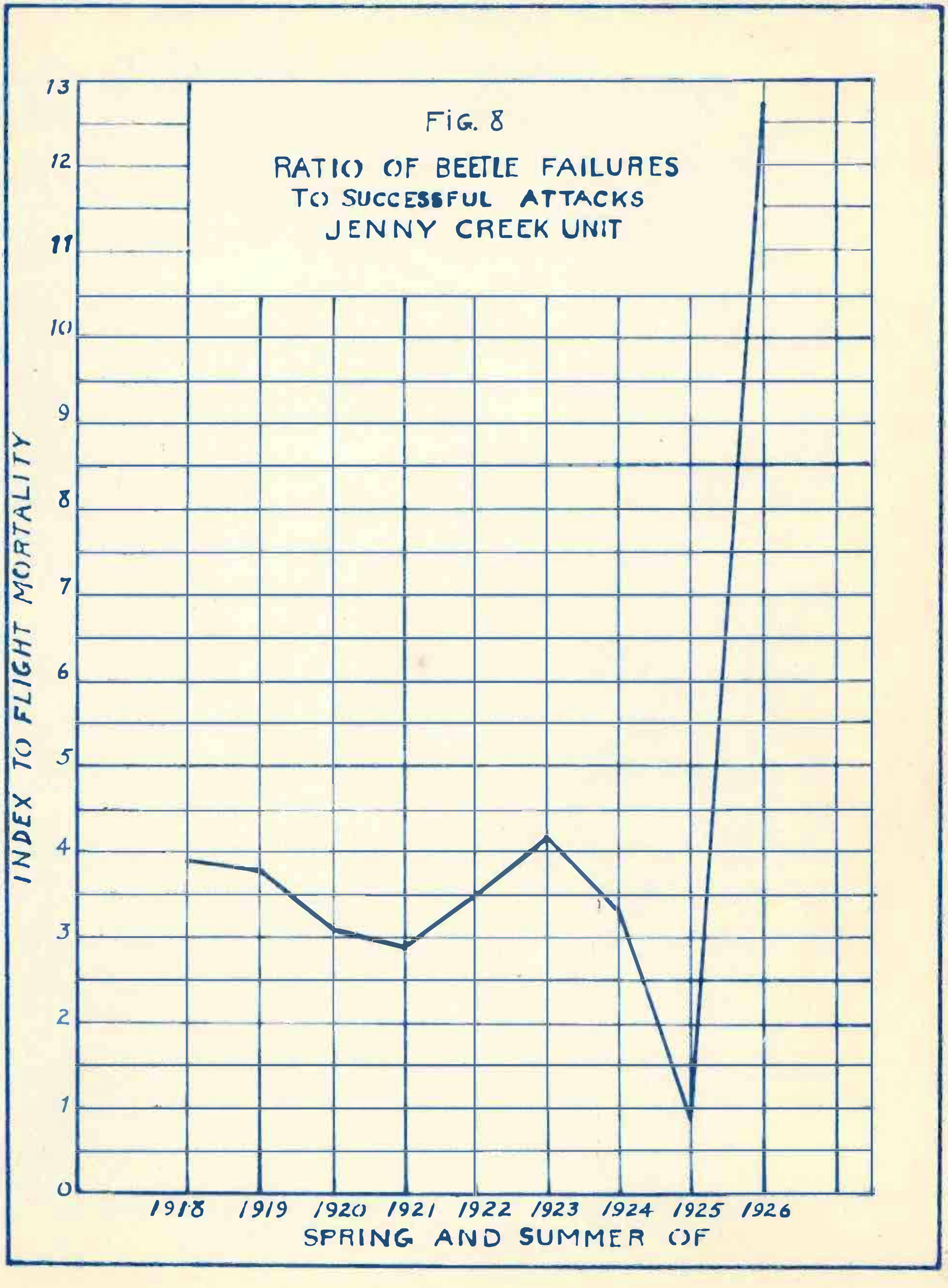


FIG. 8
RATIO OF BEETLE FAILURES
TO SUCCESSFUL ATTACKS
JENNY CREEK UNIT
INDEX TO FLIGHT MORTALITY
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1918
1919
1920
1921
1922
1923
1924
1925
1926
SPRING AND SUMMER OF

RECOMMENDATIONS FOR FUTURE STUDIES

The foregoing analysis of bark counts has shown that they are absolutely useless as a means of predicting subsequent western pine beetle infestations, and are not apt to lead to any further information that might be of value. They have brought out the fact that the most important influences operate upon the beetles after theybleave the trees and before they reach their new hosts. It is therefore recommended that our future work be directed toward discovering what these important factors are. Bark counts will not be needed in this work, since the rise and fall of epidemics can best be gauged from the continuous records on sample plots, and the factors which might influence flight mortality will have to be measured by means of weather-recording instruments, dendrographs and other paraphernalia of the ecologist.

The important thing for us to do now is to determine what causes the rise and fall of barkbeetle epidemics. In order to do this it will be necessary first to keep continuous records of the fluctuations of barkbeetle epidemics in a number of well-selected localities (this is now being done in the southern Oregon-northern California region), and second to measure for the purpose of later correlations all possible factors that we have reason to suppose may be of importance. Among these I can think of the following:

(1) Potential beetle population, as shown by emergence counts and number of trees infested in previous generation. (The present study indicates that this factor is of little importance.)

(2) Flight mortality, as affected by unfavorable weather, birds, predators and parasites, distance of flight and host resistance. (This is evidently a very important factor, upon which we have little or no information at the present time.)

(3) Quantity of susceptible host material, which is influenced by the number of slow-growing trees, fire-scorched trees, windfalls etc. (We now have considerable evidence as to the importance of the food supply in building up epidemics. This can be used in a multiple correlation with other factors to determine its significance as a cause of beetle epidemics.)

To be more specific, the study should involve the following procedure:

(1) A continuous record of infestation fluctuations on 25 or more well-selected plots over a period of 25 years or more. This record will constitute the independent variable to which the other causal factors can be related. A period of less than 25 years cannot possibly show the existence of cycles in epidemics nor give enough data for use in working out a multiple correlation of all the interrelated factors.

The records now being taken on the Southern Oregon-Northern California plots should be adequate for this purpose, since they show the number of trees and volume of loss for each year on plots large enough to be representative of the loss in that immediate locality, and we already have eight years of records on these plots to build on.

(2) To determine the influence of the dependent variables, the following records should be secured:

(a) Weather influences

At least four meteorological stations should be set up in the main forested areas adjacent to the plots and records taken for 25 years or more of such items as

(1) Rainfall--amount and seasonal distribution
(2) Humidity--daily record
(3) Temperature--maximum and minimum, dailyrecord
(4) Cloudy and bright days

(b) Birds

A measure of the activity of woodpeckers can be obtained by recording the amount of bark removed in their search for grubs, in terms of the percentage of total bark surface destroyed.

(c) Parasites and Predators

The seasonal fluctuations in parasites and predators should be taken into account, but as yet we have no means that seems at all feasible of measuring their seasonal abundance. Bark counts certainly show as great deviations as those of the Dendroctonus beetles; and since the bark must be carefully sliced to secure a count of predaceous and parasitic larvae, an unreasonable amount of work is involved.

(d) Distance of flight and host resistance

The measure of distance of flight or of the number of trees that repel insect attack can be easily secured.

(e) Quantity of susceptible host material

At the end of the period of observations, core measurements can be taken on 25 or more carefully-selected trees, and a measure of the seasonal fluctuation in growth conditions secured. For this work it will be preferable to take cores from isolated, thrifty or thrifty mature dominant trees of Class 1 (Dunning's tree classification) that have not been influenced by any change in stand or site conditions.

Records should also be kept on each plot of the quantity of fire-injured trees, windfalls or other factors that might cause an increase or decrease in the quantity of susceptible host material on the area.

(3) To determine whether or not growth rate has an influence upon the number of attacks necessary to kill a tree. Some additional bark counting of attacks should be done. A maximum error in the average of ±2 should be satisfactory for such a study, and hence 100 square feet of bark should be examined in each of the three general groups of slow-growing, medium-rate and fast-growing trees—300 square feet in all. Preferably such attacks should be made at 15 feet from the ground, and each sample should consist of a two-square-foot section, with at least two such sections from each tree. Attacks only need be counted. This should give an adequate basis upon which to draw conclusions on this point.